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PRACTICAL METHOD FOR DETECTING IRRADIATED CHICKEN AND TURKEY

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1 INTRODUCTION

This abstract details a test applicable to poultry breasts exposed to relatively low doses of gamma rays. The screen is simple, inexpensive, uses little organic solvent and is applicable to a large number of samples.

2 EXPERIMENTAL PROCEDURE

The method is based on the observation that small amounts of formaldehyde (HCHO) are generated when poultry tissue is irradiated. The HCHO is extracted following derivatisation and the derivative is estimated fluorimetrically.

3 RESULTS AND DISCUSSION

The table below shows the effect of irradiation doses on the formation of HCHO in some chicken and turkey samples. Following irradiation, the samples were stored at -18°C for approximately 2 months and analysed at 0, 1, 4, 8 and 10 weeks.

4 CONCLUSIONS

Gamma irradiation of poultry breast tissue generates HCHO in concentrations estimated to be < 10 ppm (parts per million) when doses up to 6 kGy have been applied. Under the conditions used in the experiment it was possible to distinguish irradiated from control tissue even after 2 months storage at -18°C.

The work thus far should be considered as preliminary as a number of problems must still be investigated.

Table 1 *Effect of Storage and Irradiation Dose on Sample Fluorescence*

Species	*Storage (Weeks)*	*Fluorescence Reading*					
		0 kGy	*1 kGy*	*2 kGy*	*3 kGy*	*6 kGy*	*10 kGy*
Chicken	0	20	41	103	146	396	532
	1	13	39	62	169	311	446
	4	17	33	78	107	191	318
	8	8	22	55	92	142	205
Turkey	0	14	26	98	162	327	547
	1	12	38	71	110	326	468
	4	16	37	58	100	232	371
	8	9	28	54	80	143	265
	10	10	42	111	167	316	476

Poster Presentations

Some starch-PVOH blends appear to have potential for replacing LDPE films in applications where mechanical properties are critical for intended use and good moisture barrier properties are not necessary; other starch-PVOH blends are being explored for replacement of PS in disposable food-service items. Such single-use, quickly-used food applications avoid the safety concerns related to longer-term food packaging applications. Several companies are attempting to commercialize extrudable biodegradable blends containing high percentages of starch (Ahmed et al., 1995).

Other Polysaccharide Materials. ***Alginate*** films are formed by evaporation of an aqueous alginate solution followed by ionic crosslinking with a calcium salt. They are impervious to oils and fats but are poor moisture barriers (Cottrell and Kovacs, 1980). Despite this, alginate gel coatings can significantly reduce moisture loss from foods by acting sacrificially. In other words, moisture is lost from the coating before the food significantly dehydrates. Alginate coatings are good oxygen barriers (Conca and Yang, 1993), can retard lipid oxidation in foods (Kester and Fennema, 1986), and can improve flavor, texture, and batter adhesion.

Coatings that include ***carrageenan*** as a major or sole component have been applied to a variety of foods to carry antimicrobials and to reduce moisture

Table 3 — Edible Polysaccharide Coating Applications and Functions

MATERIAL AND APPLICATION	FUNCTION OF COATING	REFERENCE
A. Cellulose		
Methyl cellulose (MC)		
Pork and poultry pieces	Breading adhesion	Bauer et al., 1969
Glucose-oxidase-catalase enzyme preparation	Inactivation protection during thermal processing	Scott, 1961
MC and hydroxypropyl methyl cellulose		
Potato products, onion rings	Oil barrier	Gold, 1969
Food pieces	Batter adhesion	Sanderson, 1981
MC and beeswax		
Brownies	Moisture barrier	Greener and Fennema, 1989
Hydroxypropyl cellulose		
Nut meats	Moisture and oxygen barrier	Ganz, 1969
Candies	Moisture barrier	Krumel and Lindsay, 1976
Carboxymethyl cellulose		
Bananas	Oxygen and carbon dioxide barrier	Banks, 1984
Apples	Oxygen and carbon dioxide barrier	Banks, 1985; Drake et al., 1987; Santerre et al., 1989; Smith and Stow, 1984
Fresh fruits and vegetables	Oxygen and carbon dioxide barrier	Lowings and Cutts, 1982
Hard cheese, hard sausage	Mold suppression	Lück, 1968
Freshly-cut celery	Moisture barrier	Mason, 1969
Pears	Oxygen and carbon dioxide barrier	Meheriuk and Lau, 1988
Tomatoes	Oxygen and carbon dioxide barrier	Nisperos and Baldwin, 1988
Oranges	Oxygen and carbon dioxide barrier	Nisperos-Carriedo et al., 1990
B. Starch		
Amylose		
Dried raisins	Clumping and sticking prevention	Moore and Robinson, 1968
Potato chips, french fried potatoes, specialty potato products	Oil barrier	Murray et al., 1971
Hydroxypropylated starch		
Confectionery product	Oil barrier	Brake and Fennema, 1993
Almond nut meats	Oxygen barrier	Jokay et al., 1967
Jellied candies, caramels	Stickiness prevention	Jokay et al., 1967
Dextrins (starch hydrolysates)		
Almonds	Moisture barrier	Murray and Luft, 1973
Freshly sliced apples	Oxygen barrier	Murray and Luft, 1973

Table 3. Continued on page 67.

loss, oxidation, or disintegration.

Low-methoxyl ***pectin***, derived by controlled de-esterification, forms gels in the presence of calcium ions and can be used to develop edible films (Maclay and Owens, 1948; Schultz et al., 1948). The WVP of pectin films is quite high, the same order of magnitude as that for plain cellophane and other carbohydrate films. The WVP can be reduced significantly by adding a wax coating onto the pectin film (Schultz et al., 1949). Although pectinate coatings are poor moisture barriers, they can retard water loss from food by acting as a sacrificing agent. Pectin coatings have been investigated for their ability to retard moisture loss and lipid migration and improve handling and appearance of foods.

Chitosan is produced commercially by de-acety-

Table 3 — continued from page 66. Edible Polysaccharide Coating Applications and Functions

MATERIAL AND APPLICATION	FUNCTION OF COATING	REFERENCE
	C. Seaweed Extracts	
Alginates		
Beef steaks, pork chops, skinned chicken drumsticks	Texture improvement and moisture barrier	Allen et al., 1963a,b
Fish	Moisture barrier	Cottrell and Kovacs, 1980; Dziezak, 1991
Breaded foods, filled dough products	Moisture, lipid, oxygen barrier	Earle and McKee, 1985
Frozen shrimp	Flavor, color, texture retention; breading adhesion	Earle and Snyder, 1966
Meat, fish, fruits, vegetables	Batter adhesion	Fischer and Wong, 1972
Ice cream	Drippings elimination	Jenkinson and Williams, 1973
Lamb carcasses	Microbial growth reduction and chill rate increase	Lazarus et al., 1976
Precooked ground pork patties	Oxygen barrier	Wanstedt et al., 1981
Beef pieces, steak	Moisture and oxygen barrier	Williams et al., 1978
Carrageenan		
Cut grape-fruit halves	Moisture barrier	Bryan, 1972
Frozen fish	Mechanical disintegration protection, moisture barrier	Guiseley et al., 1980
Poultry parts	Shelf-life extension in cold storage	Meyer et al., 1959
Poultry pieces	Oxygen barrier	Pearce and Lavers, 1949
Intermediate-moisture cheese-analog	Surface microbial growth reduction	Torres and Karel, 1985; Torres et al., 1985a,b
	D. Pectinates	
Confectionery product	Oil barrier	Brake and Fennema, 1993
Foods	Fungicide, vitamin, antioxidant carrier	Maclay and Owens, 1948
Cheese, dried sausages, ham, fish, frozen foods	Moisture barrier	Maclay and Owens, 1948; Schultz et al., 1948
Candied fruits	Stickiness reduction	Maclay and Owens, 1948; Swenson et al., 1953
Dates	Stickiness reduction and appearance improvement	Swenson et al., 1953
Almonds	Oil barrier	Swenson et al., 1953
	E. Chitin/Chitosan	
Apples, pears, peaches, plums	Oxygen and carbon dioxide barrier	Davies et al., 1989; Elson and Hayes, 1985
Fresh strawberries	Postharvest decay control	El Ghaouth et al., 1991a
Fresh cucumbers, bell peppers	Postharvest decay control	El Ghaouth et al., 1991b
Wheat seeds	Crop yields increase	Sandford, 1989
	F. Microbial Polysaccharides	
Pullulan		
Peanuts, cashew nuts, instant noodles, fried confectioneries, dried sardines, dried meat products	Oxygen barrier	Yuen, 1974
Dried vegetables	Mechanical damage reduction, oxygen barrier	Yuen, 1974
Levan		
Pharmaceuticals	Controlled release in the body	Kaplan et al., 1993

lating chitin obtained from shellfish waste. It is biodegradable but has not yet been approved as a food ingredient in the U.S. Chitosan films that are clear, tough, and flexible and good oxygen barriers can be formed by casting from aqueous solution (Kaplan et al., 1993; Sandford, 1989). Chitosan-based coatings can protect foods from fungal decay and modify the atmospheres of fresh fruits.

Pullulan, ***levan***, and ***elsinan*** are extracellular microbial polysaccharides that are edible and biodegradable. Pullulan films cast from aqueous solution are clear, odorless, and tasteless and good oxygen barriers (Conca and Yang, 1993; Yuen, 1974). Pullulan coatings have been used successfully as oxygen barriers to prolong food shelf life. Levan and elsinan also can be used as edible coating materials for foods and pharmaceuticals due to their low oxygen permeability (Kaplan et al., 1993).

Protein-based. ***Collagen*** is a fibrous, structural protein in animal tissue that can be converted into edible and biodegradable films. Because collagen is not thermoplastic, collagen film must be made by extruding a viscous colloidal acidic dispersion into a neutralizing bath followed by washing and drying. Collagen film is not as strong and tough as cellophane but has reasonably good mechanical properties (Hood, 1987). Although no data on the WVP of collagen are available, its composition suggests that it is not a good moisture barrier. Collagen film is an excellent oxygen barrier at 0% RH, but oxygen permeability (OP) increases rapidly with increasing RH in a manner similar to cellophane (Lieberman and Gilbert, 1973).

Collagen is the most commercially-successful edible protein film. Collagen casings have largely replaced natural gut casings for sausages. Except for large sausages requiring thick casings, collagen casings are eaten with the sausage. Flat collagen films on smoked meats, such as hams, prevent the outer elastic netting from becoming imbedded in the meat during cooking. The collagen film is eaten with the meat product after removal of the netting. In addition to providing mechanical integrity to meat products, collagen film functions as an oxygen and moisture barrier (Baker et al., 1994).

Additional applications of collagen film have been explored. Collagen film overwrap on refrigerated and thawed beef round steak, packaged in high barrier bags or in PS foam trays with polyvinylchloride

Table 4 — Edible Protein Coating Applications and Functions

MATERIAL AND APPLICATION	FUNCTION OF COATING	REFERENCE
	A. Gelatin	
Model food	Antimicrobial carrier	Guilbert, 1988
Meat products	Mold prevention, oxygen barrier, handling abuse protection	Keil, 1961; Keil et al., 1960
Cut-up frozen turkey meat	Oxygen barrier and antioxidant carrier	Klose et al., 1952
Smoked chicken meat	Moisture barrier	Moorjani et al., 1978
Battered and breaded meats	Frying oil barrier	Olson and Zoss, 1985
Yogurt	Fruit separation	Shifrin, 1968
Meat cuts	Oxygen and moisture barrier	Whitman and Rosenthal, 1971
	B. Corn Zein	
Zein		
Eggs	Moisture and bacteria barrier; shell strength increase	Meyer and Spencer, 1973
Rice	Vitamin adhesion	Mickus, 1955
Tomatoes	Moisture and oxygen barrier	Park et al., 1994a
Popcorn	Popping behavior	Wu and Schwartzberg, 1992
Zein-acetylated monoglyceride		
Confectioneries	Oxygen, lipid, moisture barrier; antioxidant carrier; and stickiness prevention	Alikonis, 1979; Cosler, 1957, 1959
Almonds, peanuts, pecans, walnuts	Oxygen, lipid, moisture barrier; antioxidant carrier	Alikonis and Cosler, 1961; Cosler, 1958a,b,c
Intermediate-moisture food	Preservative carrier	Torres et al., 1985a,b
Zein-vegetable oils		
Nuts, confectioneries, pharmaceuticals	Oxygen and moisture barrier, antioxidant carrier	Andres, 1984
Zein/vegetable wax-oil laminate		
Dried fruit	Stickiness prevention; antioxidant carrier	Gunnerson and Bruno, 1990
	C. Wheat Gluten	
Nuts	Salt binding	Noznick and Bundus, 1967

Table 4. Continued on page 69.

(PVC) film, reduced exudation without significantly affecting color or lipid oxidation (Farouk et al., 1990). Another study found that collagen film performed as well as plastic film in maintaining the quality of frozen beef cubes (Conca, 1994; Rice, 1994). Collagen film, unlike synthetic polymer film, melts away as the meat thaws and cooks, eliminating need for plastic film waste handling.

Gelatin is obtained by hydrolytic cleavage of collagen chains. Edible coatings with gelatin reduce oxygen, moisture, and oil migration or can carry an antioxidant or antimicrobial (Table 4). Gelatin can also encapsulate low-moisture or oil-phase food ingredients and pharmaceuticals. Encapsulation protects against oxygen and light and defines ingredient amounts or drug dosages (Reineccius, 1994).

Other proteins that have been studied for film formation include ***corn zein*** (CZ), ***wheat gluten*** (WG), ***soy protein isolate*** (SPI), ***whey protein isolate*** (WPI), and ***casein*** (CS). Edible and biodegradable films from these proteins are generally obtained from ethanolic solution (CZ and WG) or aqueous solution (CZ latex, SPI, WPI, and CS). These films have mechanical properties similar to collagen film and inferior to cellophane (Brandenburg et al., 1993; Butler and Vergano, 1994; Gennadios et al., 1990; McHugh and Krochta, 1994a; Stuchell and Krochta, 1994). The poor mechanical properties of these protein films likely limit biodegradable packaging film applications, but paper coatings or edible food coatings are possibilities (Gennadios et al., 1994; Trezza and Vergano, 1994). These protein films have fairly large WVPs (Avena-Bustillos and Krochta, 1993; Gontard et al., 1992; McHugh et al., 1994; Park and Chinnan, 1995; Stuchell and Krochta, 1994). Their WVPs can be lowered by including wax or other lipid materials in the formulation (Avena-Bustillos and Krochta, 1993; Gontard et al., 1994; McHugh and Krochta, 1994b; McHugh and Krochta, 1994c). Such protein composite films, however, have not attained the low WVP of cellulose-ether-based composites. The OPs of films made from CZ, WG, SPI and WPI are quite low at 0–50% RH (Butler and Vergano, 1994; Gennadios et al., 1993; Li et al., 1993; McHugh and Krochta, 1994a). As with collagen film, RH has a large effect on OP for films from these materials. Little work has been done on the aroma-barrier properties of biodegradable and edible

Table 4 — contined from page 68. Edible Protein Coating Applications and Functions

MATERIAL AND APPLICATION	FUNCTION OF COATING	REFERENCE
	D. Casein	
Casein-acetylated monoglyceride		
Zucchini	Moisture barrier	Avena-Bustillos et al., 1994a
Apples and celery sticks	Moisture barrier	Avena-Bustillos et al., 1997
Frozen fish	Moisture barrier	Hirasa, 1991
Casein-stearic acid, beeswax, or acetylated monoglyceride		
Peeled carrots	Moisture retention	Avena-Bustillos et al., 1993, 1994b
	E. Whey Protein	
Whey protein		
Freeze-dried chicken dice	Mechanical disintegration protection	Alcantara et al., 1997
Peanuts	Oxygen barrier	Maté and Krochta, 1997; Maté et al., 1996
Frozen salmon	Antioxidant carrier	Stuchell and Krochta, 1995
Whey protein, whey protein/acetylated monoglyceride		
Breakfast cereal, raisins, diced cheese, peas	Moisture barrier, stickiness prevention	Chen, 1995
	F. Additional Materials	
Albumen, gelatin		
Chicken parts	Breading adhesion	Suderman et al., 1981
Albumen, soy protein		
Raisins	Moisture barrier	Bolin, 1976; Watters and Brekke, 1961
Albumen, soy protein, wheat gluten		
Battered meats, etc.	Batter adhesion	Baker et al., 1972
Casein, gelatin, soy protein, or zein/fatty acid amylose ester		
Dried fruits and vegetables	Moisture and oxygen barrier	Cole, 1969
Albumen, casein, gelatin, zein		
Nuts	Color carrier	Johnson, 1969
Albumen, casein, gelatin, soy protein-vegetable oil		
Baked and fried goods,chocolate	Oxygen and moisture barrier	Durst, 1967

films. The aroma permeability of WG film, however, was found to be only one-tenth that of LDPE (Debeaufort and Voilley, 1994).

Besides collagen and gelatin, ***corn zein*** is the only other protein that has been promoted commercially as an edible film or coating. The barrier, vitamin adhesion, and antimicrobial carrier properties of zein film coatings have been used on a variety of foods. Zein is also used on pharmaceuticals for coating capsules for protection, controlling release, and masking flavors and aromas (Gennadios et al., 1994). Zein-coated paper was judged equal to PE-laminated paper for quick-service restaurant packaging of fatty foods and was found to have good heat-sealing characteristics (Trezza and Vergano, 1994, 1995). Zein has also been explored as a plant-based replacement for animal-derived collagen in the manufacture of sausage casings (Turbak, 1972) and for the production of water-soluble pouches for dried foods (Georgevits, 1967).

Wheat gluten has been explored as a plant-based replacement for collagen in the manufacture of sausage casings (Mullen, 1971; Schilling and Burchill, 1972; Turbak, 1972) and as a means to improve the adherence of salt and flavorings to nuts and of batters to meats and other foods.

Soy protein has also been studied for the manufacture of sausage casings (Turbak, 1972) and in the production of water-soluble pouches (Georgevits, 1967). Soy protein in edible coating applications can improve batter adhesion and reduce moisture migration in raisins and dried peas.

Casein has been investigated for use in the production of water-soluble pouches (Georgevits, 1967). Caseinate coatings retained sorbic acid on the surface of a model food system and on the surfaces of intermediate moisture fruits and, when combined with lipid, protected fresh vegetables, dried fruits and vegetables, and frozen fish from moisture migration and/or oxidation.

Whey protein coatings effectively carried antioxidants for frozen fish, significantly reduced oxygen uptake and rancidity in roasted peanuts, and reduced disintegration of freeze-dried food. Whey protein and whey protein-acetylated monoglyceride coatings also reduced moisture migration into breakfast cereal and reduced stickiness of raisins.

Microbial Polyesters. Polyhydroxyalkanoates (microbial polyesters) can be produced by nutrient-limited fermentation of sugar feedstock. By manipulation of the growth medium, a random copolymer containing both hydroxyvalerate (HV) and hydroxybutyrate (HB) is obtained. The resulting copolymer poly(3-hydroxybutyrate)-co-(3-hydroxyvalerate) (PHB/V) is thermoplastic and fully biodegradable (Timmins et al., 1993). By changing the ratio of HV to HB, the resulting copolymer can be made to resemble either polypropylene (PP; low HV) or PE (high HV), with regard to flexibility, tensile strength, and melting point (Kemmish, 1993). Polyhydroxybutyrate (PHB) is strong, stiff, and brittle, but HV content improves flexibility and toughness (Holmes, 1988). PHB/V has good chemical and moisture resistance (Kemmish, 1993) and is reported to possess good oxygen, moisture, and aroma barrier properties (Anonymous, 1993b). Good moisture resistance and barrier properties are consistent with the fact that PHB/V is relatively more hydrophobic than polysaccharides and proteins commonly used in biodegradable and edible films. Furthermore, while the oxygen barrier may not be as good as that for polysaccharides and proteins at low RH, it should not be as sensitive to increasing RH.

Uses being considered for PHB/V include beverage bottles, coated paperboard milk cartons (Hocking and Marchessault, 1994), and films (Ahmed et al., 1995).

Polylactic Acid. Polylactic acid (PLA) is a thermoplastic, biodegradable polymer based on lactic acid produced by fermentation of simple sugars. PLA-based materials have performed well in commercial medical applications, such as bioabsorbable sutures and implants. PLA can be easily hydrolyzed back to lactic acid, using only water, and then can be repolymerized (Ahmed et al., 1995). This may provide some advantages in recycling PLA. Recent advances have produced more economical PLA polymers of sufficient molecular weight to possess other useful properties. PLA has mechanical properties similar to PS (Sinclair, 1994). Modification of molecular weight and crystallinity results in properties that can also mimic PE, PP, or PVC (Gruber, 1994). Several U.S. and Japanese firms are developing PLA-based polymers (Ahmed et al., 1995). Product targets include food service containers and utensils, grocery bags, and compostable waste bags.

Conclusion

Edible Polymer Films. The hydrophilic nature of edible polymers limits their ability to provide desired edible film functions. For all edible polymers, RH, which greatly influences properties, must be taken into account when considering applications. Use of edible polymer films and coatings as moisture barriers usually requires the formation of composite films that contain hydrophobic materials such as edible fatty acids and waxes. Cellulose ether-based composite films with moisture barrier properties comparable to LDPE involve formation of polymer-lipid bilayers from aqueous ethanolic solutions and/or lamination with wax. These films and coatings have greater integrity than lipid or wax structures alone. Elimination of ethanol and the second application (lamination) step, however, would increase the usefulness of this concept. Additional research is needed to develop such composite films and coatings from cellulose ethers and other edible polymers without need for non-aqueous solvents and/or multiple steps.

Because edible polymers can hydrogen bond effectively, they make good oxygen, aroma, and lipid barrier films at low-to-intermediate RH. Additional data on the effect of RH are needed to identify the range of practical use. Nonetheless, the barrier deteriorates with increase in RH. Therefore, potential applications include: (1) protective pouches or coatings for low-moisture food products vulnerable to oxidation or aroma loss in conjunction with a simple, moisture-barrier packaging film bag (e.g., LDPE); (2) respiration-reducing coatings for fresh fruits and vegetables that are exposed to low RH during storage and transportation; and (3) lipid-barrier films or coatings separating lipid-rich ingredients from other components of heterogeneous foods. Edible polymers that are water-soluble and good emulsifiers may be favored in many food coating applications. Development of composite bilayer films will allow protection of edible film oxygen, aroma, and lipid barrier properties with a hydrophobic moisture barrier layer. Synthetic polymer films, e.g., EVOH copolymer, that are good oxygen and aroma barriers tend to be expensive. The additional cost incurred in coating or pouching foods with an edible film may be balanced by savings in eliminating such synthetic oxygen/aroma barriers in multi-layer packages. Simplifying the package may also make it more recyclable, another advantage with economic consequences.

The mechanical properties of edible polymer films are generally inferior to synthetic films. The films, however, are adequately durable casings, wraps, or coatings on food products. They are also likely to adequately separate layers of heterogeneous foods or as small food pouches/bags.

Opportunities presented by the thermoplastic nature of certain edible polymers should be explored to enable production of edible films by extrusion. Potential materials include certain cellulose ethers, starch compounds, and certain proteins.

When considering possible edible film coating applications, attention must be given to the requirement that edible coating formulations must wet and spread on the food surface and upon drying form a film coating that has adequate adhesion, cohesion, and durability to function properly. These properties are influenced by both edible film formulation and methods of coating and drying. Lack of attention to these facts has probably resulted in inconsistent and unsatisfactory results in many studies. In addition, edible coatings must provide satisfactory appearance, aroma, flavor, and mouthfeel. Selective application to appropriate foods and good control of environmental conditions are necessary to ensure microbial stability. Addition of antimicrobials to edible films may widen application possibilities. Finally, any advantage of edible film coatings must be provided at an affordable cost. Unfortunately, little published research is available on food coating issues, sensory properties, microbial stability, or economics of edible films.

Biodegradable Polymer Films. For biodegradable packaging materials to compete with nonbiodegradable synthetics, the critical mechanical, optical, and/or barrier properties for the intended application must be matched. This is especially difficult in the case of moisture barrier properties, because no biodegradable polymer approaches the hydrophobic character of synthetic polymers such as LDPE. Because of their inherent hydrophilic nature, biodegradable polymers are usually poor moisture barriers. They are, however, naturally good oxygen barriers at low RH, but oxygen permeabilities increase exponentially as RH increases.

Cellulose-based films have been used most extensively among biodegradable polymers. In spite of not being thermoplastic, cellophane has a significant presence commercially in food packaging, with use of coating and lamination to improve its properties. Coating with a nitrocellulose-wax (NC-W) blend provides a moisture barrier comparable to LDPE without sacrificing biodegradability, but at greater cost. Such coating allows short-term use in packaging of fresh bread, meat, and produce, and long-term packaging of low-moisture foods. Coating with the NC-W moisture barrier layer also helps retain oxygen barrier characteristics at medium to high RH.

Nonetheless, to develop economically viable biodegradable polymers for packaging, developers should use conventional synthetic polymer packaging conversion technology. For many uses, a combination of starch and PVOH can form thermoplastic blends that can be extruded to form films with mechanical properties similar to LDPE. Different starch-PVOH blends can be used to mold semi-rigid products currently produced from PS. PLA is a versatile thermoplastic material with properties that can also be modified to resemble LDPE or PS. PHB/V copolymer is a thermoplastic material that has adjustable properties dependent on the monomer ratio. PHB/V appears to have greater moisture resistance and lower WVP than the other biodegradable polymers. These properties could allow production of beverage bottles, coated milk cartons, and other containers useful for high-moisture products where starch-PVOH or PLA could not be used.

Several companies have commercialized starch-PVOH, PLA, and PHB/V polymers. None of the resulting products has obtained FDA approval for use in long-term food packaging (Beach and Ahmed, 1993a,b). PLA, however, has been self-determined GRAS by a major manufacturer (Thorsheim, 1996). Nonetheless, the key markets for biodegradable polymers for the nearer term include: nonfood packaging; personal and health care items; refuse (composting) and retail bags; loosefill packaging peanuts; medical gloves, gowns and masks; agricultural mulches and potting containers; and fast-food containers, cups, plates, and cutlery. Short-term use of these biodegradable polymer products in fast-food service applications avoids concern over premature biodegradation with longer-term packaging of high-water-activity foods. With all biodegradable polymers, the biodegradation characteristics must be taken into account when considering packaging applications, package storage conditions, and potential for insect infestation and microbial food safety problems.

Other issues related to biodegradable polymers must be considered. Easy, efficient sorting of biodegradable from non-biodegradable packaging would be essential to avoid contamination of recycling and biodegradation efforts (Evans and Sikdar, 1990). Secondly, designing a package to biodegrade precludes its being used as a resource for other products (Van Volkenburgh and White, 1993). Thirdly, biodegradation is slow and produces significant methane, with greenhouse-effect implications. In comparison, properly-designed incineration is fast and efficient and can capture important energy from natural (renewable/biodegradable) and synthetic polymers alike (Rowatt, 1993). Finally, biodegradable polymers are usually considerably more expensive than conventional synthetic polymers. Improvements in production practices, economies of scale, and increasing costs for fossil resources could all be necessary to produce a more favorable economic situation for biodegradable polymers.

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